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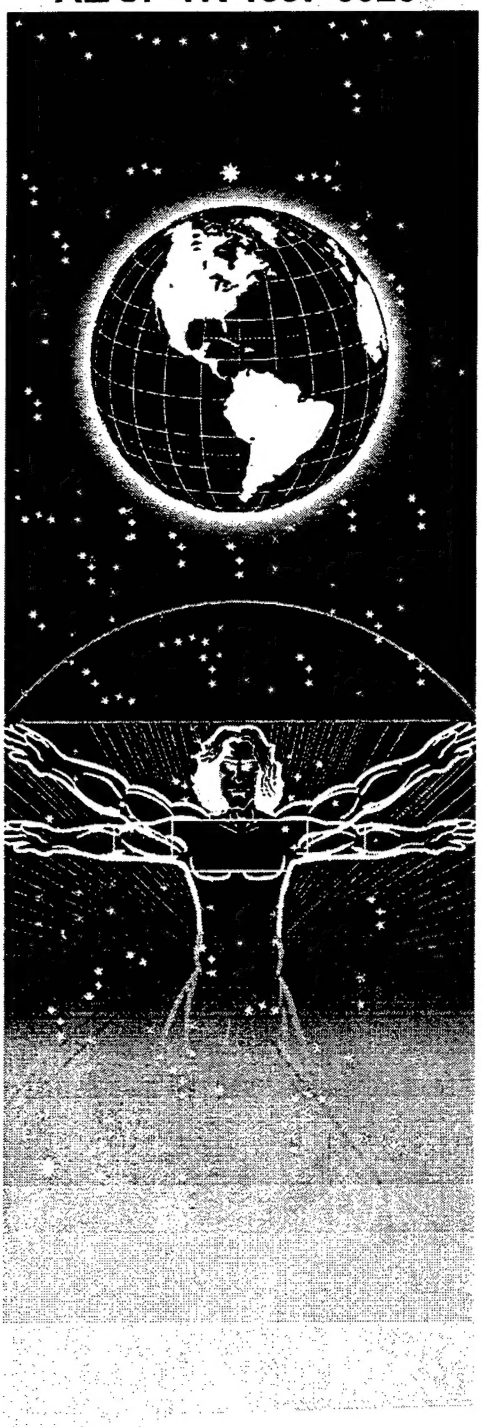

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Electrophysiological Correlates of +Gz Tolerance Comparison Study

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July 1996

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This report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	JULY 1996	Final May 1996-July 1996

4. TITLE AND SUBTITLE

Electrophysiological Correlates of +Gz Tolerance Comparison Study

5. FUNDING NUMBERS

6. AUTHOR(S)

Charles S. Lessard, Jonathan French, Paul Werchan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Armstrong Laboratory (AFMC)
Crew Systems Directory
Crew Technology Division
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Brooks Air Force Base, TX 78235-5104

8. PERFORMING ORGANIZATION REPORT NUMBER

AL/CF-TR-1997-0020

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release: distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes an evaluation of a helmet mounted system; presently, under development for determination of +Gz induced loss of consciousness (G-LOC). The G-LOC detection system, self-contained and built into a standard flight helmet, consists of a set of dry electrodes, preamplifiers, signal conditioning circuits, and analog-to-digital converter for acquisition of the electroencephalogram (EEG) and electro-oculogram (EOG) signals. The study compares the the EEG activity acquired with the dry electrode system to EEG activity acquired with throw-away, electrocardiogram wet electrodes. Six volunteers were selected from fully qualified centrifuge subjects at Armstrong Laboratory. Each subject experienced the same acceleration profile. In three subjects, the beginning of the M-1 straining maneuver could easily be determined from the 3-D dry electrode EEG spectral plots, which may imply that significant motion artifact or low frequency components of the EMG are in the EEG signal. The rapid rise in EEG low frequencies (less than 4-Hz), when the subject began the M-1 straining maneuvers are not as obvious from the 3-D wet electrode EEG spectral plot. No G-LOC could be seen, precluding any comments on G-LOC. The results indicate that the dry electrode system is susceptible to motion artifacts that result in large-magnitude; low frequency signals. High-frequencies (24 to 36 Hz) were observed in the 3-D wet electrode EEG of two subjects, which were not as noticeable in the 3-D dry electrode EEG spectral plot. Part of the high-frequencies probably reflect muscle artifact of activity from the reference electrode.

14. SUBJECT TERMS	15. NUMBER OF PAGES
EEG; Dry Electrodes; Wet Electrodes; +Gz; Spectral Analyses; Centrifuge; Human Subjects	36
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

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ELECTROPHYSIOLOGICAL CORRELATES OF $+G_Z$ TOLERANCE

Charles S. Lessard, Jonathan French, Paul Werchan

INTRODUCTION

The purpose of this study was to evaluate a helmet mounted system; presently under development for determination or detection of +Gz-induced loss of consciousness (G-LOC). The G-LOC detection system, self-contained and built into a standard flight helmet, consists of a set of dry electrodes, and built-in preamplifiers, signal conditioning circuits, and analog-to-digital converter for acquisition of the electroencephalogram (EEG) and electro-oculogram (EOG) signals. Reports from animal studies indicate shifts or increases in the delta activity of the EEG immediately preceding G-LOC [1]; however, there is no scientific evidence to indicate that a similar increase in delta activity occurs in pilots who are actively countering the loss of consciousness. In fact, little information is available describing brain electrical activity changes at elevated +Gz. This report compares the EEG activity acquired with the dry electrode system to EEG activity acquired with throw-away, electrocardiogram (ECG), paste electrodes (wet electrodes). Additionally, the EEG activity at different, constant +Gz levels were compared and examined for possible trends in the EEG.

SUBJECTS

Six volunteers were selected from fully qualified centrifuge subjects at the United States Air Force (USAF) Armstrong Laboratory. Each subject was individually fitted with a dry electrode helmet; placements of the dry electrodes were checked; and the sites for the wet electrodes were prepared, before attachment of the electrodes. After preparation, the wet electrode-skin impedance was measured. The helmets were prepared for each wearer based on 3-D skull topography to ensure a tight form fit.

Each subject experienced the same experimental protocol (acceleration profiles) in a single session of one-hour duration. The first acceleration-profile was a rapid onset to +2Gz followed by two-minutes at a constant +2Gz level; subsequently, the subject was given three-minutes of rest at +1Gz prior to any additional maneuver. The entire sequence of the acceleration profiles was as follows:

1. Rapid onset to +2Gz level for 2-minutes; rest for 3-minutes at +1Gz.
2. Gradual linear increase in acceleration from +1Gz to +9Gz in a period of approximately 90-seconds.
3. Rapid deceleration from +9Gz to +1Gz in 10-seconds; rest for 3-minutes at +1Gz.
4. Rapid onset to +5Gz for 15 seconds; rest for 3-minutes at +1Gz.
5. Rapid onset to +7Gz for 15 seconds; rest for 3-minutes at +1Gz.
6. Rapid onset to +9Gz for 15 seconds; rest for 3-minutes at +1Gz.
7. Standard air combat maneuver(SACM).

The SACM consists of repeated exposures to +4.5Gz for 15-seconds followed immediately, by a rapid onset to +7Gz for 15-seconds. The SACM sequence of changing +Gz exposure is continued until either the subject, medical monitor, or the centrifuge controller terminates the exposure. Termination of the sequence is based on any one of the following factors: subject reporting 100% loss of peripheral lights, subject reporting fatigue, subject G-LOC, or an

abnormal medical physiologic response determined by the medical monitor. During the experimental exposures to acceleration, each subject wore a standard anti-G suit (CSU-13B/P) and was seated in an upright seat at 13-degrees.

Five subjects wore oxygen masks which were not connected to any oxygen delivery system. One subject did not wear a mask; the reference electrode for this subject was placed on the cheek (Infra-orbital region). Placement of the reference electrode for the wet electrodes varied among the five subjects who wore oxygen masks; for 3 subjects the reference electrode was placed on the right cheek (Infra-orbital region) and for the other 2 subjects the reference placement was on the jaw hinge (styloid process). Of the three subjects whose reference electrode was secured on the right cheek bone below the center of the eye (Infra-orbital region), one subject's reference electrode was totally hidden by the oxygen mask. On another subject, the reference electrode was about 60% obscured by the oxygen mask. On the third subject, the reference electrode was totally visible and touching the oxygen mask. The reference electrodes placed on the right jaw-hinge of two subjects were completely obscured by the oxygen mask. See Figure 1.

DATA ACQUISITION METHOD

The data acquisition method utilized for this study was as follows. Four dry electrodes (compressed silver-silver-chloride: Ag-Ag-Cl) and four wet electrodes were used to record the electroencephalograms (EEG) and electro-oculograms (EOG) from six volunteer subjects. Placements of the electrodes did not conform to the standard 10-20 clinical EEG montage, but were based on the subject's helmet fitting and available bare-skin contact surface for the dry electrode. Two dry electrodes were placed on the forehead without preparation or gel approximately one centimeter above the outer canthus of each eye, and two other dry electrodes were located about one centimeter below the outer canthus of each eye on the flat structure of the zygomatic region.

The dry electrodes were mounted in the visor area of the helmet and were held in place by spring tension. The spring apparatus was adjustable and necessary to preclude contact between the dry electrodes and any part of the helmet or mask, in order to avoid inducing motion artifacts in the EEG signals. The two dry electrodes on the forehead were used as the difference pair of active electrodes for acquiring a channel of differentially recorded EEG referenced to one of the dry electrodes on the cheek bone (zygomatic region). The non-reference dry electrode, on the other cheek bone, was used with the most distal electrode on the forehead to differentially record the EOG signal. Reference for the EOG signal was the same reference electrode used for EEG recording.

Three ECG recessed paste (wet) electrodes were used to record the EEG for comparison with recordings from the dry electrodes. Two wet electrodes were placed on the forehead above the eyebrow and as close to the dry electrodes as the circular adhering disk would permit. Reference for the wet electrodes was placed under the mask about one centimeter below the center of the subject's right eye. Two subjects had the reference wet electrode placed under the mask near the right jaw hinge (styloid process); unfortunately, this reference electrode site was over the masseter muscle which tends to increase electromyogram (EMG) activity in the EEG recording when the subject closes the glottis and performs straining maneuvers. Additionally physiological movements of inhalation, exhalation, and talking appeared to induce low frequency noise or motion artifacts in the EEG recordings.

Dry and Wet Electrode Locations

DR is Dry Reference Electrode

WR is Wet Reference Electrode

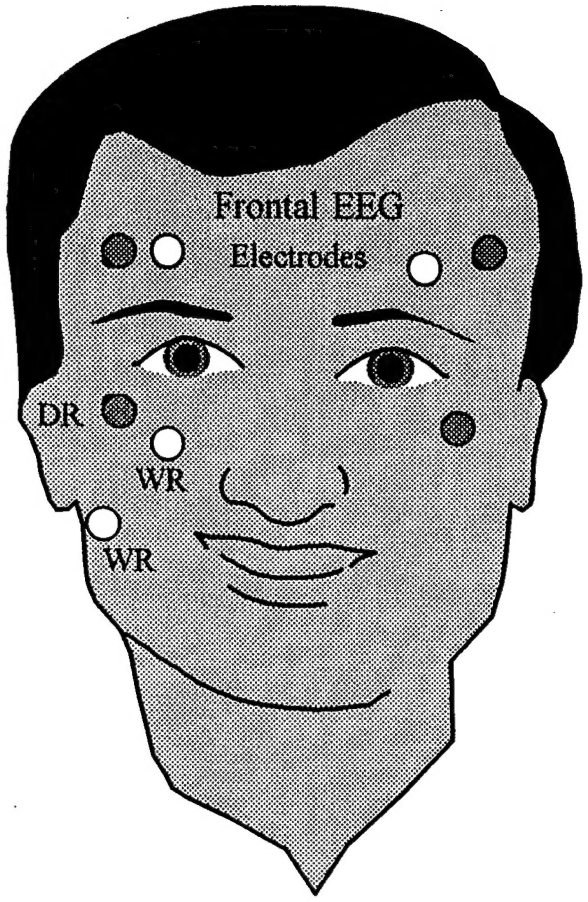


Figure 1. Sketch of EEG electrode placements. Dry EEG electrodes are solid filled circles, whereas, the recessed paste ECG electrodes used to record EEG are referred to as the Wet EEG electrodes and are the unfilled circles. Electrodes used as reference are marked as DR for Dry Reference and WR for Wet Reference.

The EEG signals from the dry electrodes were high-pass filtered at 0.5 hertz (Hz) and low-pass filtered at 30 Hz with a five-pole Butterworth filter. The dry electrode amplifier gain was set at a multipling factor of 10^4 or 10,000. While filter settings for EEG signals from the wet electrodes were the same as the dry electrodes, the gain appears (from post analysis) to be 10 times less. EEG and EOG signals from the dry and wet electrode systems were digitized at 128 Hz with a 16-bit analog-to-digital (A/D) converter. The digital data were stored onto the flash memory of a laptop computer inside the centrifuge. The flash memory was downloaded between runs to other temporary data storage devices for subsequent analysis.

Three accelerometers were mounted on the subject's helmet to record three orthogonal axis of acceleration (x, y, z,). Data from the accelerometers were digitized at 32 Hz. A total of eight channels were recorded with, 2-EEGs, 2-EOGs, 1-EMG, and 3-acceleration axes. Emphasis was placed on the comparison of dry and wet electrode EEG recordings during increased +Gz-loading. Data from neither the EOG nor the rectified, integrated EMG were analyzed in this study. Data from one of the subjects could not be downloaded from the flash memory. Several runs from another subject could not be analyzed, because the output from the dry electrode system indicated saturation of the EEG amplifier.

DATA ANALYSIS

Digitized EEG data from the dry electrode system, the wet electrode system, and the accelerometers (x, y, z axes) were imported into the digital signal processing software called "DADiSP" which stands for Data analysis and Display Software by the DSP Development Corporation, Cambridge, MA. The DADiSP program permited extraction of data segments from a data file; therefore, 15-second segments at constant acceleration were extracted from each subject's EEG file. The accelerometer data was used to determine which start and stop timing points were to be used in the extraction of a segment. Use of the accelerometer data assures that the EEG segment to be extracted was taken from the timing at a constant +Gz level or during the gradual acceleration to +9Gz.

Subsequent processing of the data segments included removal of the DC-component (DC-offset), calibration, scaling, and power spectral analysis via a mixed-radix Fast Fourier Transform (FFT) algorithm. Each EEG spectrum was exported as an ASCII, series data file for subsequent feature or parameter extraction. The resulting spectrum extended to 64 Hz, but only the frequencies from 1 to 40 Hz were of interest in the EEG analysis. The spectrum was divided into ten bands of four-Hz band width which corresponded to the standard clinical EEG frequency bands, i.e., Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-12 Hz), Beta-1 (12-16 Hz), etc., to Beta 7 (36-40 Hz); thus, thirty parameters obtained from the spectrum include:

a. total power in a band;
b. average power in a band; and
c. relative power in a band

Total power in a band is the summation of power within a clinical band. Average power in a band is the total power in a band divided by the number of spectral points in the band. Relative power in a band is the total power in the band divided by the total power in the entire spectrum. Relative power is the normalized spectrum and is expressed in percentage (%)in the comparison charts. An example for subject D-1 is shown in Figure 2.

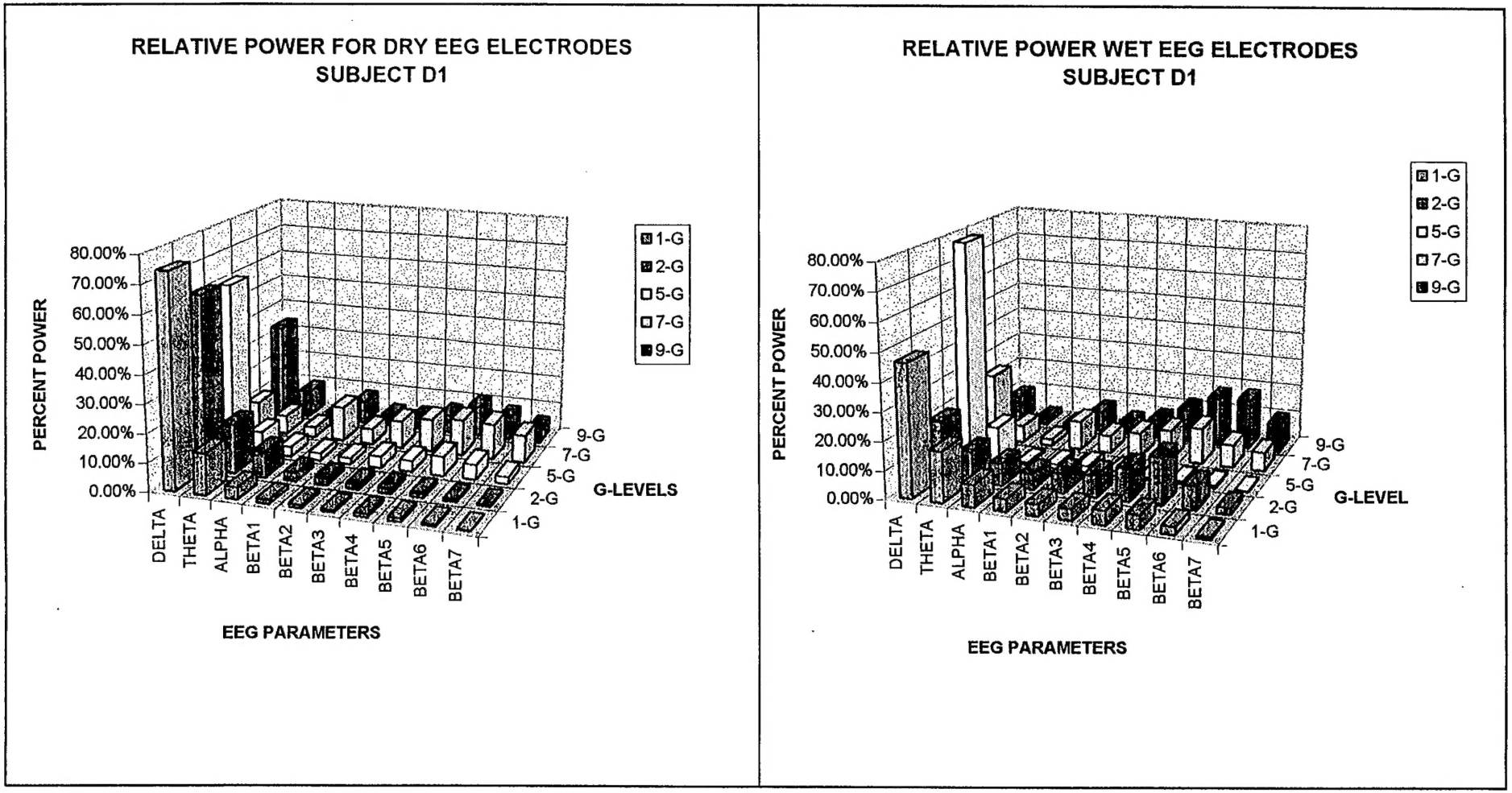


Figure 2. 3-D Bar Charts from subject D 1 present comparative views of the relative power in the clinical EEG frequency bands at various constant +Gz levels for the Dry and Wet EEG signals.

In addition to analysis of the EEG data at constant +Gz levels, the gradual linear acceleration from +1Gz to +9Gz was evaluated using a three-dimension (3-D), spectral waterfall analysis and display. As in the previous analyses, the accelerometer channel was used to determine the extraction points. For this analysis, the y-axis accelerometer signal was used for the base in an overplot. The 90-seconds of the y-accelerometer segment and the same period of EEG segment were raveled or further subdivided into 30-subsegments. The power spectrum was calculated via the FFT for the first subsegment and the information was stored for subsequent plotting. A second spectrum was calculated with the last 75% of the data points in the first segment and the first 25% of the data points in the second segment. This operation is the equivalent of taking a window one-thirtieth (1/30) of the total data set and calculating a spectrum the size of the window as the window is moved one-fourth of its width over the entire data set. A total of 120 spectra were calculated and displayed on one 3-D plot with frequency on the x-axis, time on the y-axis, and magnitude of the spectra on the z-axis. In this study, the accelerometer segment was raveled first (30-segments with 75% overlay), the color was changed to red for ease of separation from the EEG, then the EEG was raveled (waterfall) and overplotted in yellow on the accelerometer 3-D plot. The resulting 3-D plots of subject D-1 are shown in Figures 3 and 4, as examples. Similar waterfall plots for two subjects are presented in Appendix B, the others are in Figures 6 - 9.

RESULTS AND DISCUSSION

Constant Level of Acceleration

The Microsoft EXCEL software package was used to reduce the high-resolution spectra into 10 EEG bands (4 Hz bandwidth) and 30 EEG parameters. EXCEL spreadsheets were used to organize the data for plots (3-D bar-charts) to show variation of clinical EEG bands with +Gz levels. The most useful set of parameters was the Relative Power, since this measure corresponded to the normalized power spectra. In Figure 5, the average per cell was obtained from the four subjects whose data could be analyzed. The charts show large amounts of delta activity in the EEG; however, the dry EEG system had a greater percentage of delta when compared with the wet EEG system. Of more interest was the increase of high frequencies in the Beta bands (Beta 3 to Beta 6 or from 24 to 36 Hz), as the G-level increased to +9Gz. The high frequency increase was greater and easier to note in the wet EEG chart than in the dry EEG chart. Bar charts for all subjects are in Appendix A.

Additionally, a series of simple paired t-tests were run for a comparison of the signal comparability between the dry and wet EEGs. No difference between the electrical EEG signals from the dry and wet systems were predicted for the statistical comparison. The significance level for the paired t-test was set at alpha equal to 5%. In view of the small number of subjects and, consequently, the low power of the test, TABLE I is presented with caution because, in most cases, the null hypothesis was "not rejected". TABLE I shows that, in some cases, the null hypothesis was rejected in favor of the alternate hypothesis that "there is significant difference in the EEG signals between the dry and wet systems," particularly for Beta-bands 4 through 7 at the +9Gz level. This implies that the differences were large enough to be observed, even with a small sample.

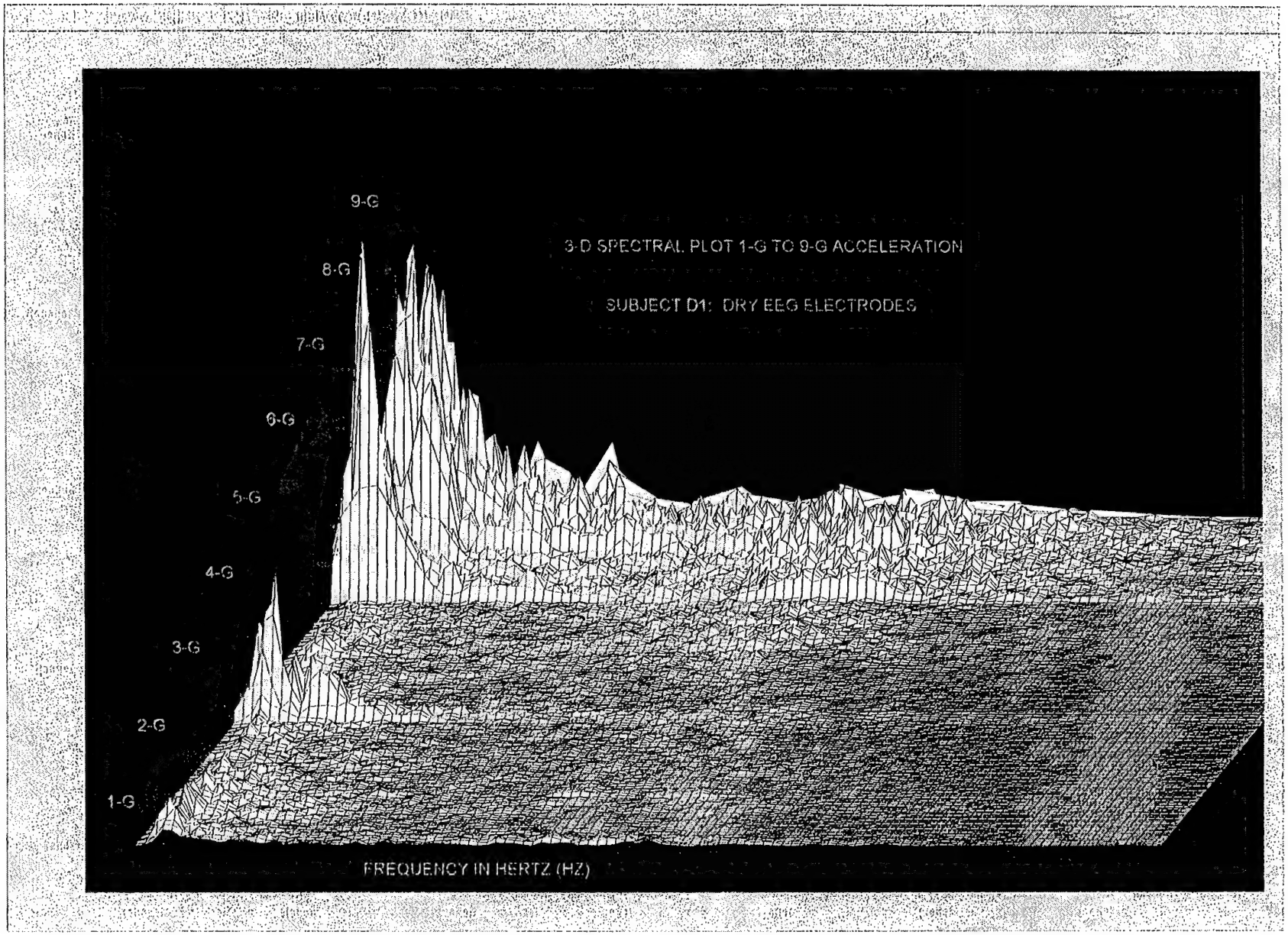


Figure 3. 3-D Spectral plot of the Dry EEG signals as subject D 1 is accelerated from +1Gz to +9Gz in 90-seconds. It is noticed that the subject begins to actively counter the +Gz forces at approximately +5Gz.

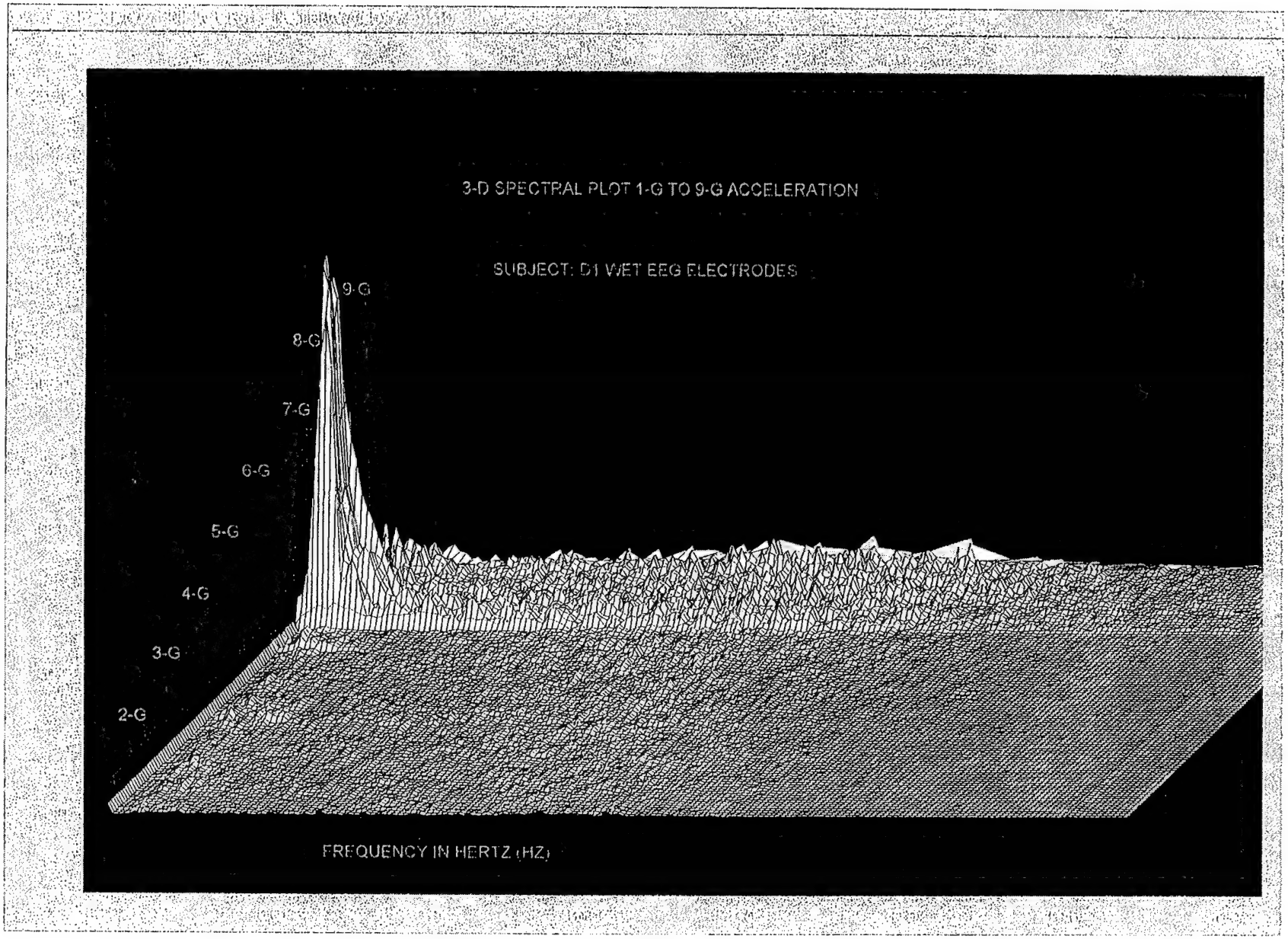


Figure 4. 3-D Spectral plot of the Wet EEG signals as subject D 1 is accelerated from +1Gz to +9Gz in 90-seconds. It is noticed that the subject begins to actively counter the +Gz forces at approximately +5Gz.

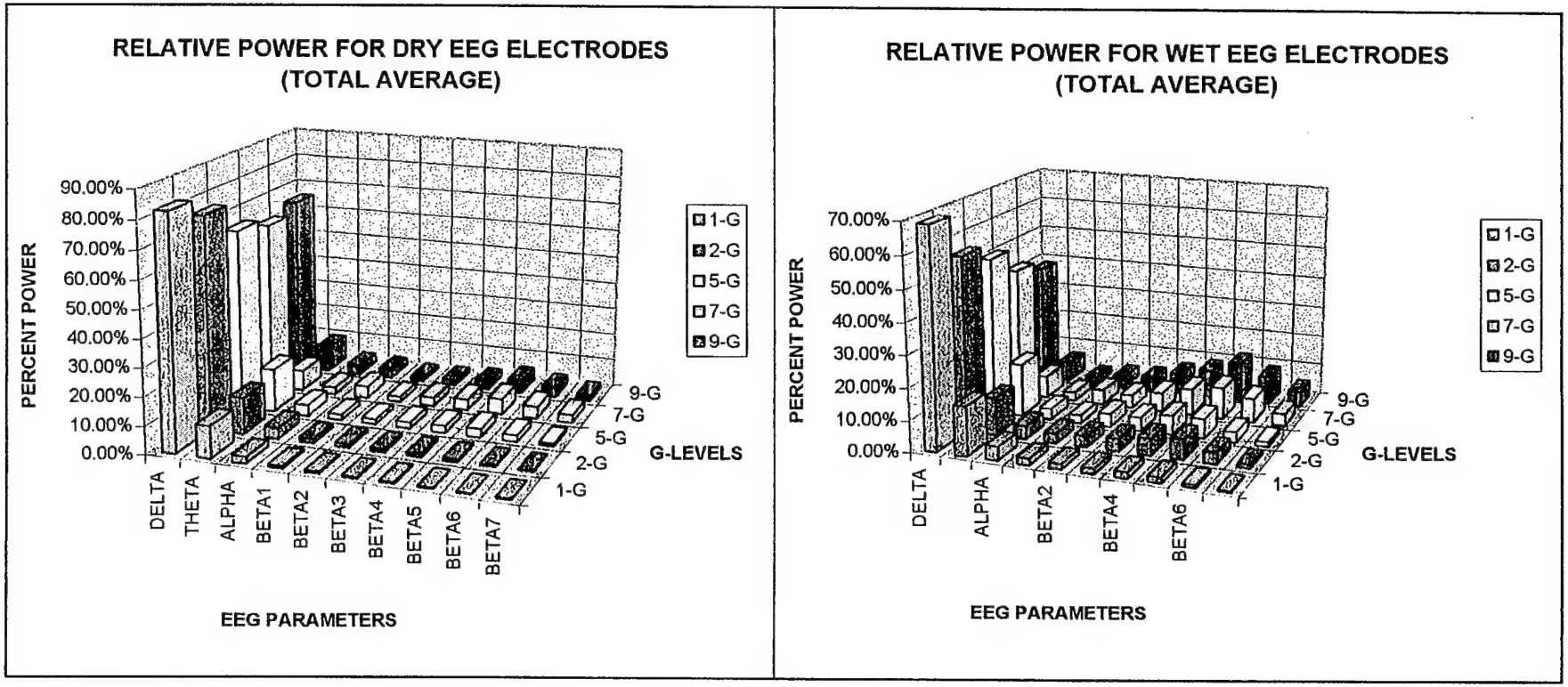


Figure 5. 3-D Bar Charts of the Averaged Relative Power from all subjects is presented for comparative views of the relative power in the clinical EEG frequency bands at various constant +Gz levels for the Dry and Wet EEG signals. The Dry EEG Electrode recordings contain significantly greater intensities of power in the Delta band. The Wet EEG recordings show an increase of high frequencies (24 - 36 Hz) as the +Gz level increases.

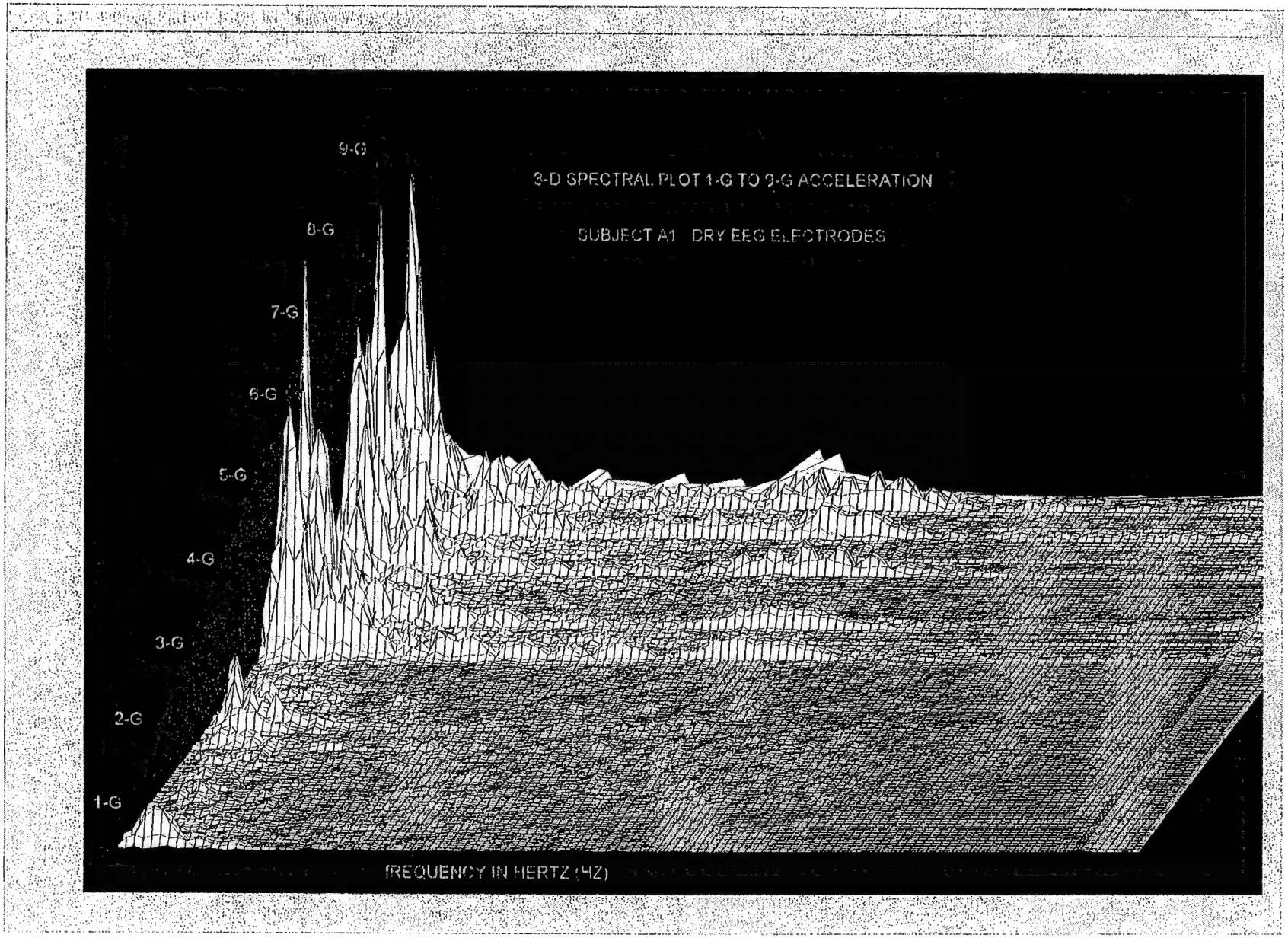


Figure 6. 3-D Spectral plot of the Dry EEG signals as subject A 1 is accelerated from +1Gz to +9Gz in 90-seconds. It is noticed that it is easy to identify when the subject begins to actively counter the +Gz forces.

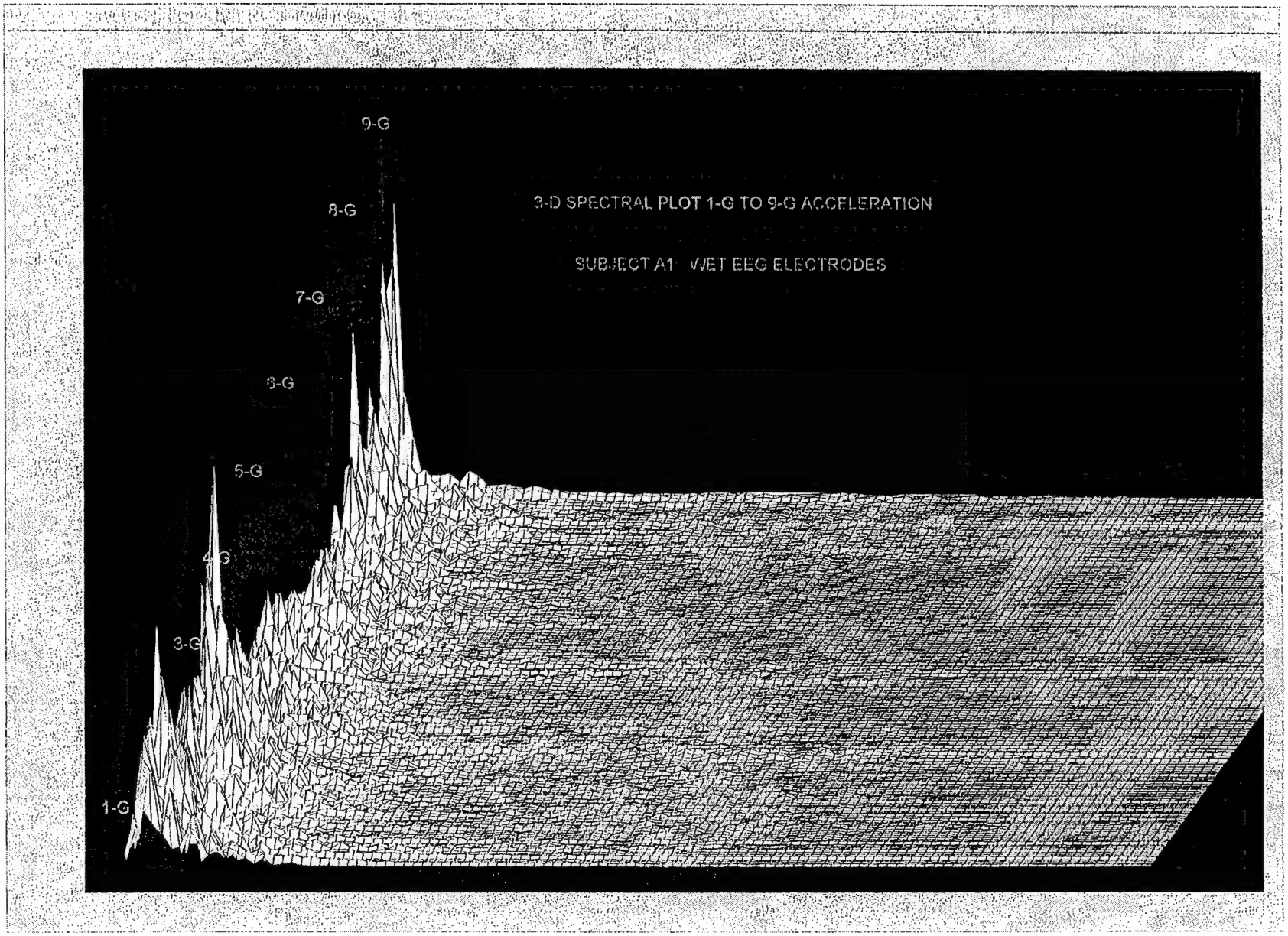


Figure 7. 3-D Spectral plot of the Wet EEG signals as subject A 1 is accelerated from +1Gz to +9Gz in 90-seconds. It is noticed that it is difficult to identify when the subject begins to actively counter the +Gz forces.

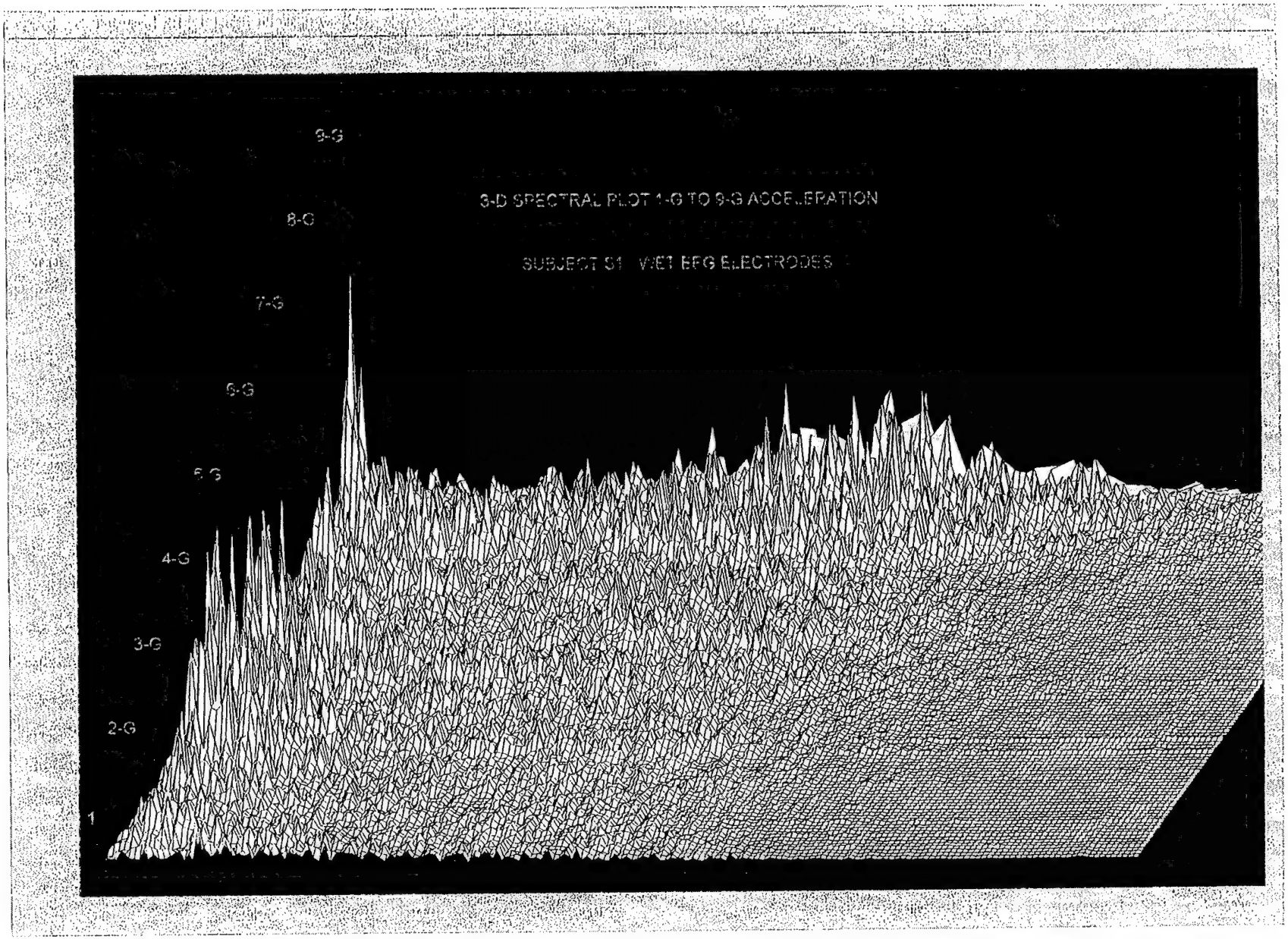


Figure 8. 3-D Spectral plot of the Wet EEG signals as subject S 1 is accelerated from 1+Gz to +9Gz in 90-seconds. The reference electrode for this subject was placed near the styloid process on the masseter muscle which introduced EMG into the EEG recording resulting in the increase of high frequencies (24 - 36 Hz) as the +Gz level and straining increased.

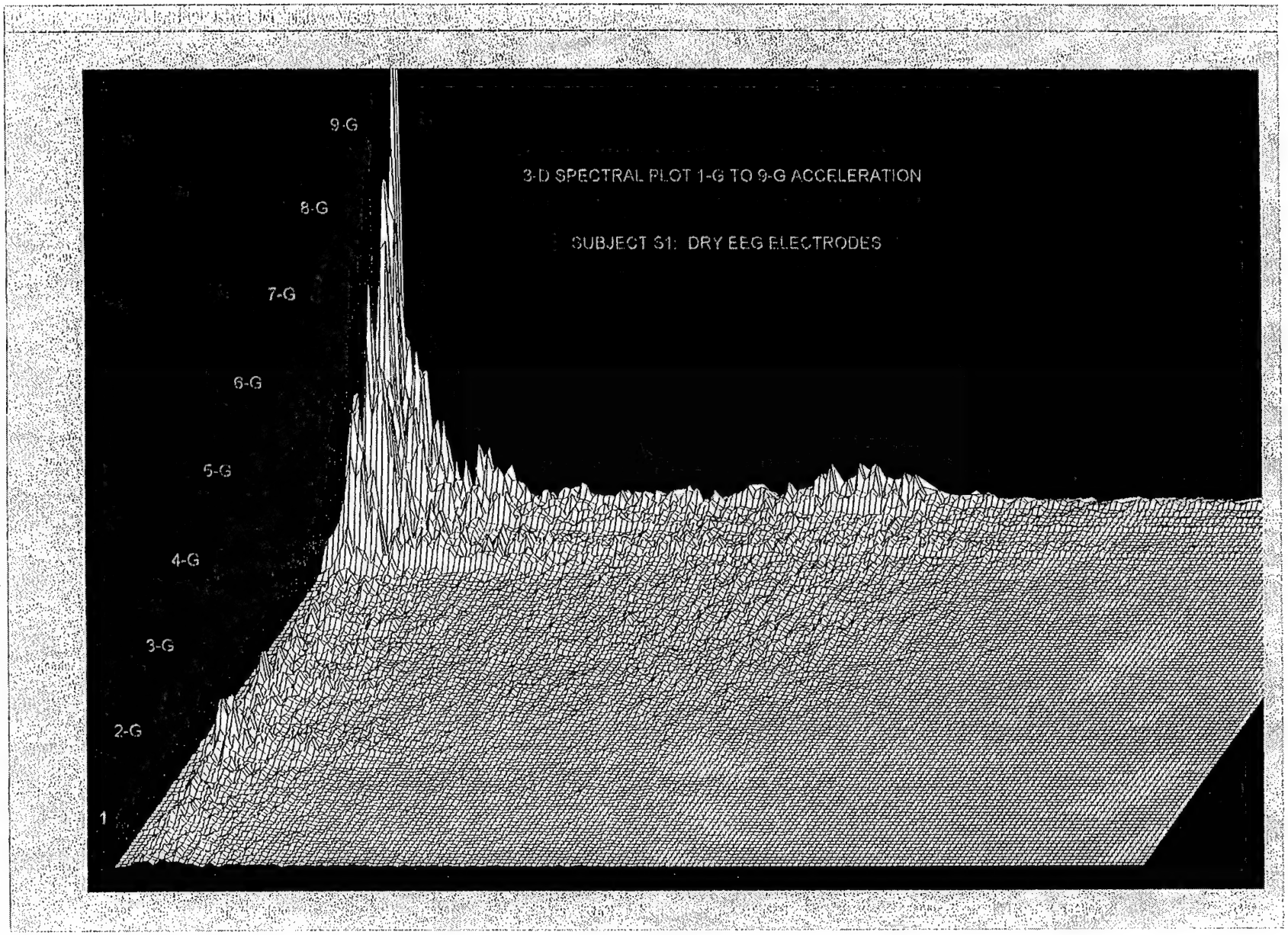


Figure 9. 3-D Spectral plot of the Dry EEG signals as subject S 1 is accelerated from +1Gz to +9Gz in 90-seconds. It is noticed that the subject begins to actively counter the +Gz forces at approximately +7Gz, and that a very modest increase of high frequencies (24 -36 Hz) is observed at +8.5Gz level.

TABLE I
RESULTS OF PAIRED t-TEST

Probability of Critical Value of T being less than the calculated t-statistics

Gz-LEVEL ' = 0.05 sig lev EEG BANDS	1-Gz 2-tail	2-Gz 2-tail	5-Gz 2-tail	7-Gz 2-tail	9-Gz 2-tail
DELTA	-	.079	-	-	-
THETA	-	-	-	-	.078
ALPHA	.091	-	-	-	-
BETA 1	-	.039	-	-	-
BETA 2	-	.067	-	-	-
BETA 3	-	.096	-	-	-
BETA 4	-	-	-	-	.075
BETA 5	-	-	-	-	.021
BETA 6	-	-	-	-	.048
BETA 7	-	.098	-	-	.022

NOTE: Criterion level of significance; V = 0.05.

Gradual +1Gz to +9Gz Acceleration

The DADiSP 3-D spectral plots of the gradual acceleration from 1-Gz to the 9-Gz level presented an interesting panorama of the EEG signal acquired with the dry electrode helmet mounted system. In most subjects, the onset of large-magnitude, low-frequencies in the delta band corresponded to the onset of the subject's straining maneuver to counter the loss of peripheral vision during high +Gz levels.

The onset of each subject's straining maneuver was extracted from the timing and +Gz levels which were simultaneously recorded on video tape taken during the exposures. The video tapes were primarily used to review the subject's response at the various +Gz levels. The 3-D spectral plot of the EEG has the corresponding 3-D spectral plot of the +Gz level on the y-axis. The spectrum of the accelerometer signal is indicated as a linearly increasing magnitude (increasing +Gz level) at DC or at the frequency equal to zero Hz. Table II compares the Gz-level at the onset of straining as measured visually verses the +Gz level at the onset of straining as measured from the dry electrode and wet electrode EEG 3-D spectral plots.

TABLE II
COMPARISON OF ONSET OF STRAINING

+Gz level at Onset of Straining During +1Gz to +9Gz

SUBJECT	VIDEO TAPE	3-D DRY EEG PLOT	3-D WET EEG PLOT
A1	4.86	5.0	N/A
D1	6.73	6.8	6.5
J1	6.70	3.0 **	3.8 **/6.7
L1	5.85	3.7*/6.8	5.8
S1	7.18	7.2	3.2*/7.8

NOTES: * Low frequency noise from undetermined source
** subject was talking from 2.8-Gz to 3.9-Gz

In three subjects (Table II: A1, D1, and S1), the +Gz levels as determined from the video recordings and the 3-D dry electrode EEG spectral plots were in agreement with the acceleration level at which the subjects began straining maneuvers. However, the start of staining was identified earlier than the video for subjects J1 and L1; in the case of J1 the low frequency signals were from the subject talking during acceleration from 2.8 to 3.9 +Gz. In the case of subject L1 the low frequency appear to be from movement of the mask which may infer that significant motion artifacts or low frequency EMG was evident in the EEG signals of subjects J1 and L1. The instantaneous jump in the low frequency activities (less than 4-Hz) that coincided with the beginning of the M-1 straining maneuver could easily be determined from subject's (A-1) 3-D dry electrode EEG spectral plots (Fig. 6). The same rapid rise, in EEG low frequency activities, was not as obvious from the subject's 3-D wet EEG spectral plot (Fig 7) to determine when the subject began the M-1 straining maneuver. No G-LOC, nor any antecedent behavioral events were seen, precluding any comments on electrophysiological correlates of G-LOC.

CONCLUSIONS AND RECOMMENDATIONS

A fundamental problem with the dry electrode system is the susceptibility to motion artifacts that results in large-magnitude, low frequency signals in the delta and theta bands. Another complication arises from the placement of the EEG electrode leads; placing dry electrodes on the forehead near the temple results in noise or artifact in the EEG signals that are not brain electrical activities; for example, eye blinks and ocular movements contaminate the lower magnitude EEG signals.

Similarly, placement of the reference electrode (in recordings of EEG with the wet electrodes) over the masseter muscle of the jaw introduces EMG signals into the EEG recordings.

The high-frequencies (24 to 36 Hz) observed in the 3-D wet electrode EEG spectral plot of subject S1 (Fig. 8), which were not as noticeable in the 3-D dry electrode EEG spectral plot of subject S1 (Fig. 9), may in part be accounted for by the placement of the reference electrode.

Under an optimal environment, e.g., controlled laboratory conditions without motion, the EEG recordings from the dry and wet systems may be similar or well correlated; however, in the centrifuge environment, the spectral plots and bar graphs of the EEG showed high frequencies, about 24 to 36 Hz, which correspond more with EMG frequencies than with normal EEG frequencies. Studies to answer the question, "Are these signals predominantly, EEG or EMG?" have yet to be conducted.

Regardless of whether the EEGs from the dry electrode system were the same or different as those from the wet electrode system, or whether the signal was really EEG or EMG, a pertinent question is, "Can an algorithm be developed to accurately detect G-LOC?" If the answer is yes, the next question should be, "Can an algorithm be developed to accurately predict the onset of G-LOC in a pilot?"

It is recommended that a study be conducted to evaluate EEG and EMG signals from alternate electrode placements in order to characterize parameters which may serve as indicators of +Gz-induced loss of consciousness. The following suggestions are made for a follow-on study.

1. Record EEG signals from the occipital and/or parietal areas of the head instead of the forehead.
2. Use standard EEG electrodes instead of the ECG recessed paste electrodes.
3. Record EMG signals from the abdominal or the back of the leg (gastrocnemius) muscles using standard EMG paste electrodes.
4. Record EEG signals from the frontal area of the head (same locations as the helmet mounted electrodes) using the dry electrode (without a helmet), as well as, wet electrodes for comparison.
5. Do not record the EOG, but use the video recordings to annotate eye-blink times for possible identification and removal from the EEG signals.

REFERENCES

1. Burns, J.W., Werchan, P.M., Fanton, J.W., and Dollins, A.B., "Performance Recovery in the Baboon Following +Gz-Induced Loss of consciousness," Technical Report: AL/CF-TR-1993-0110, AF/CFT, Brooks, AFB, TX., Dec. 1993.

The authors acknowledge the support of Alysia Sagi-Dolev.

APPENDIX A

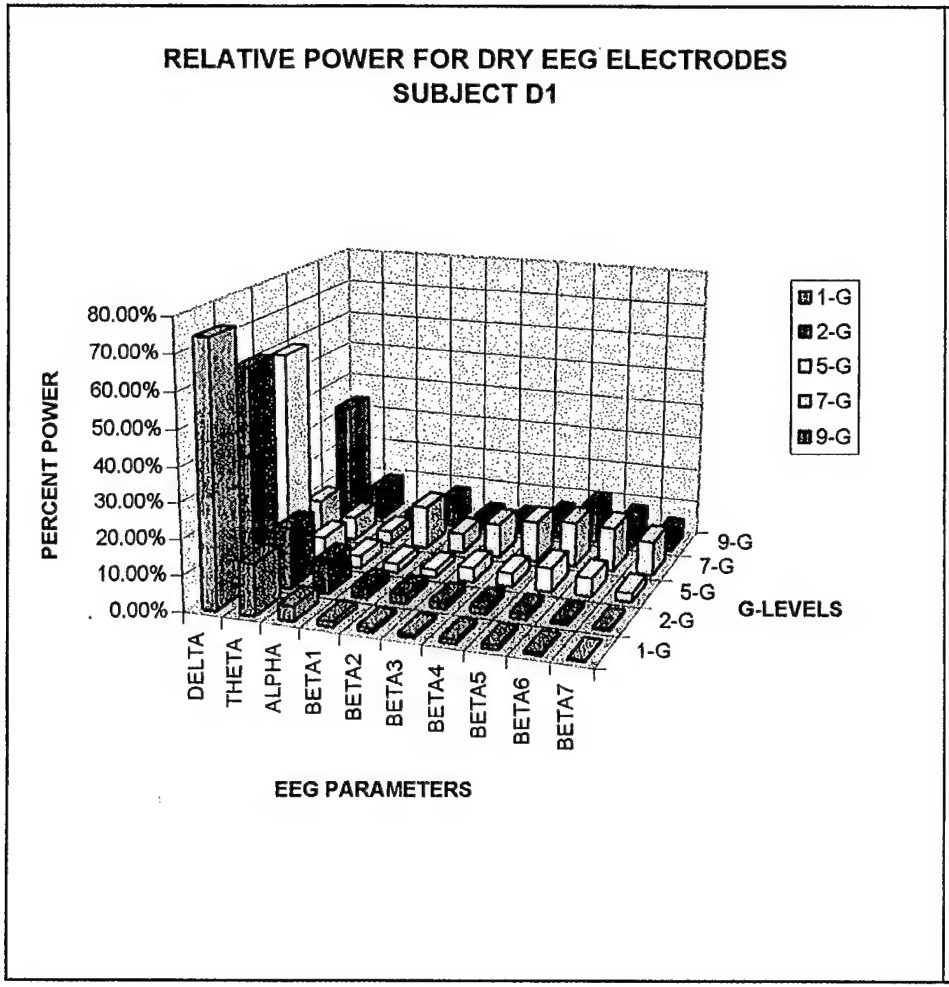
3-D Bar Charts of Relative Power

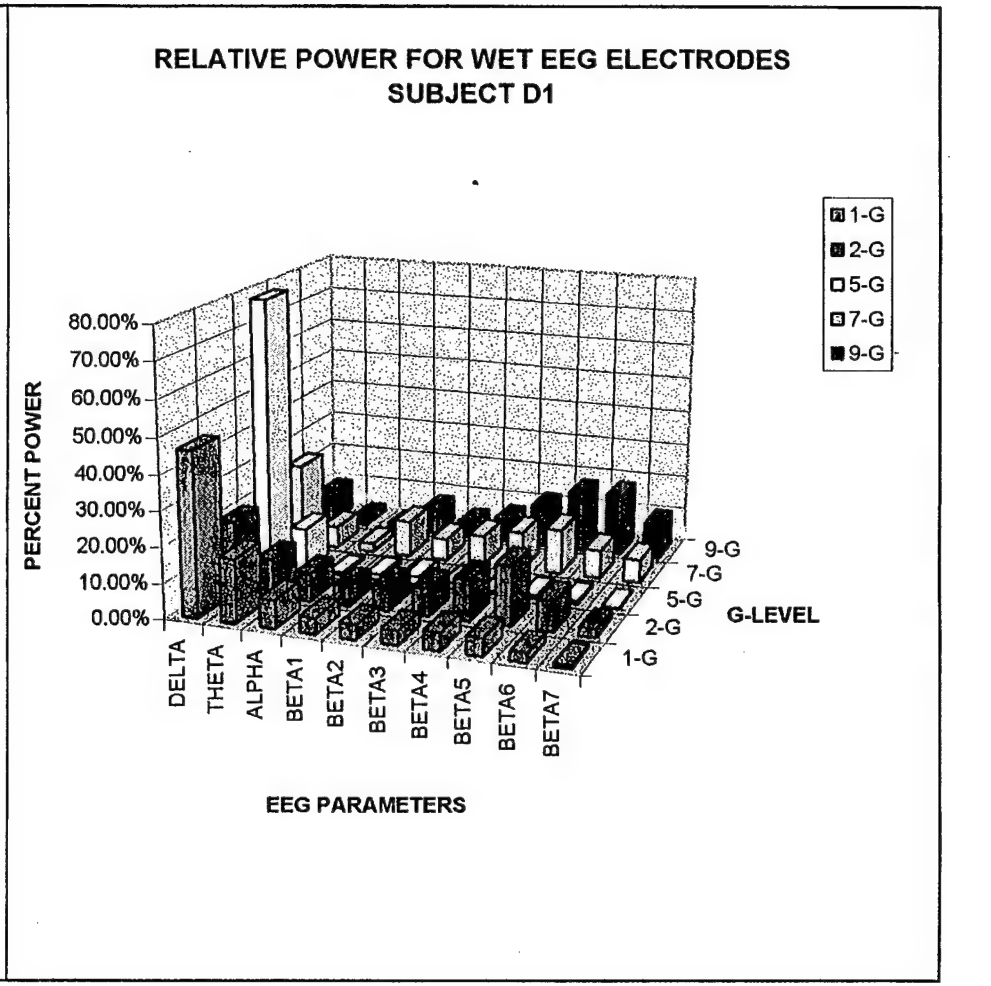
of

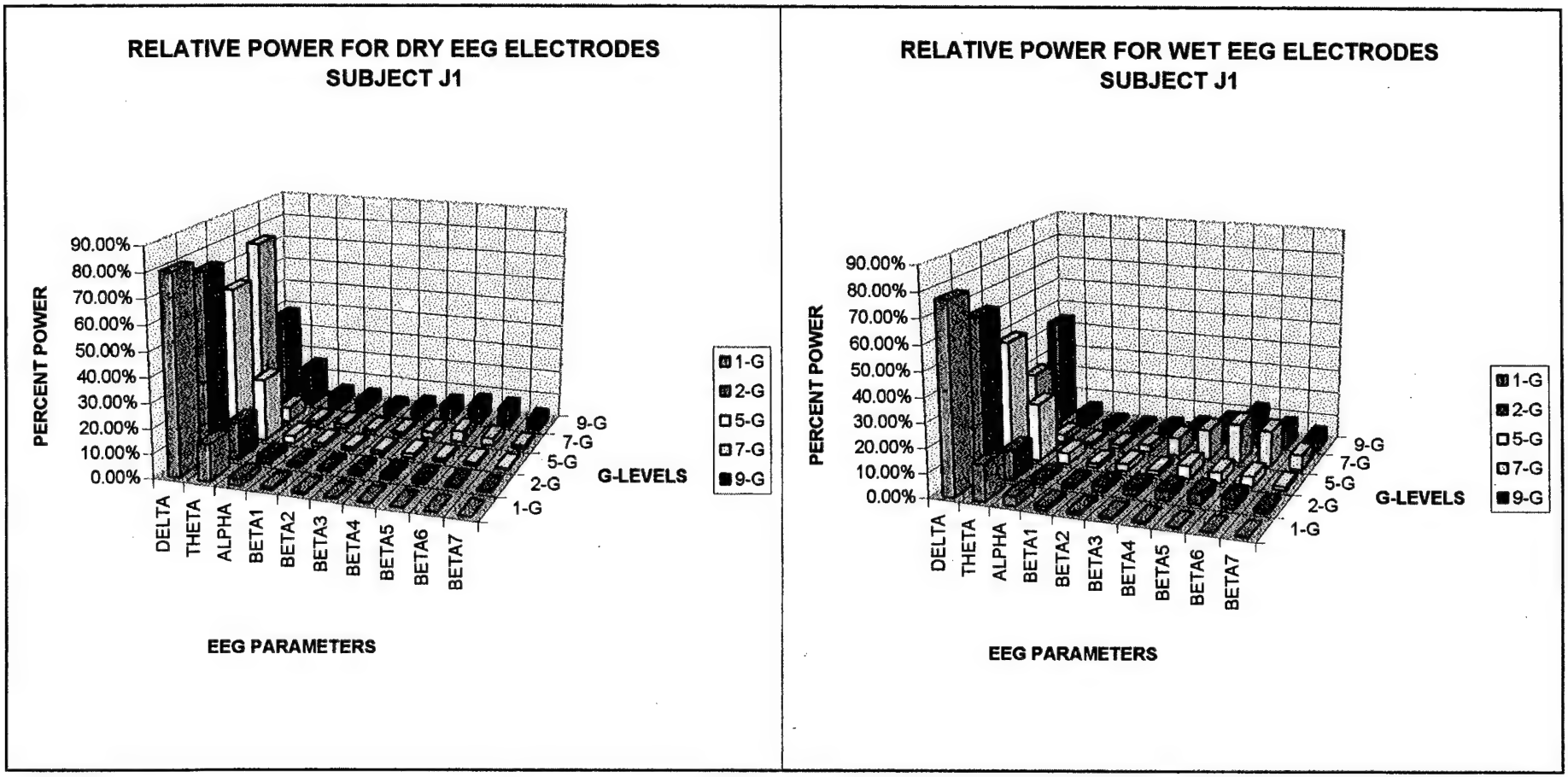
Clinical EEG Frequency Bands

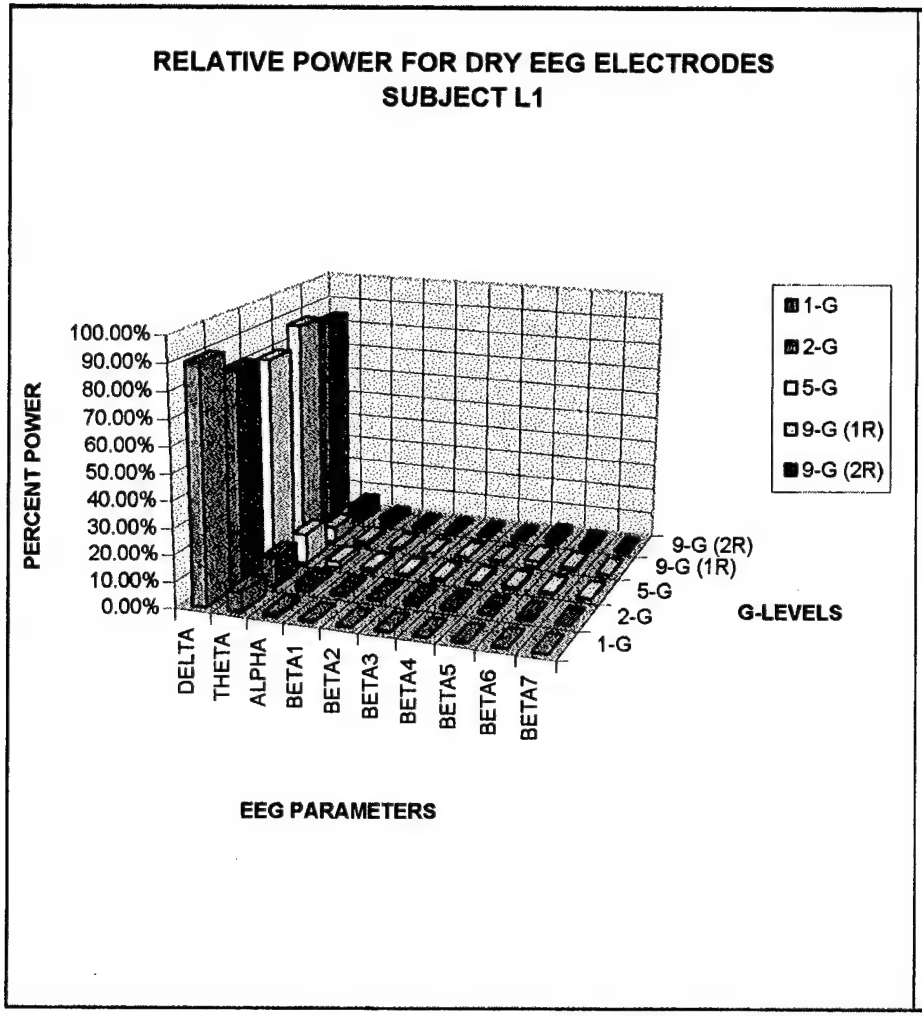
at

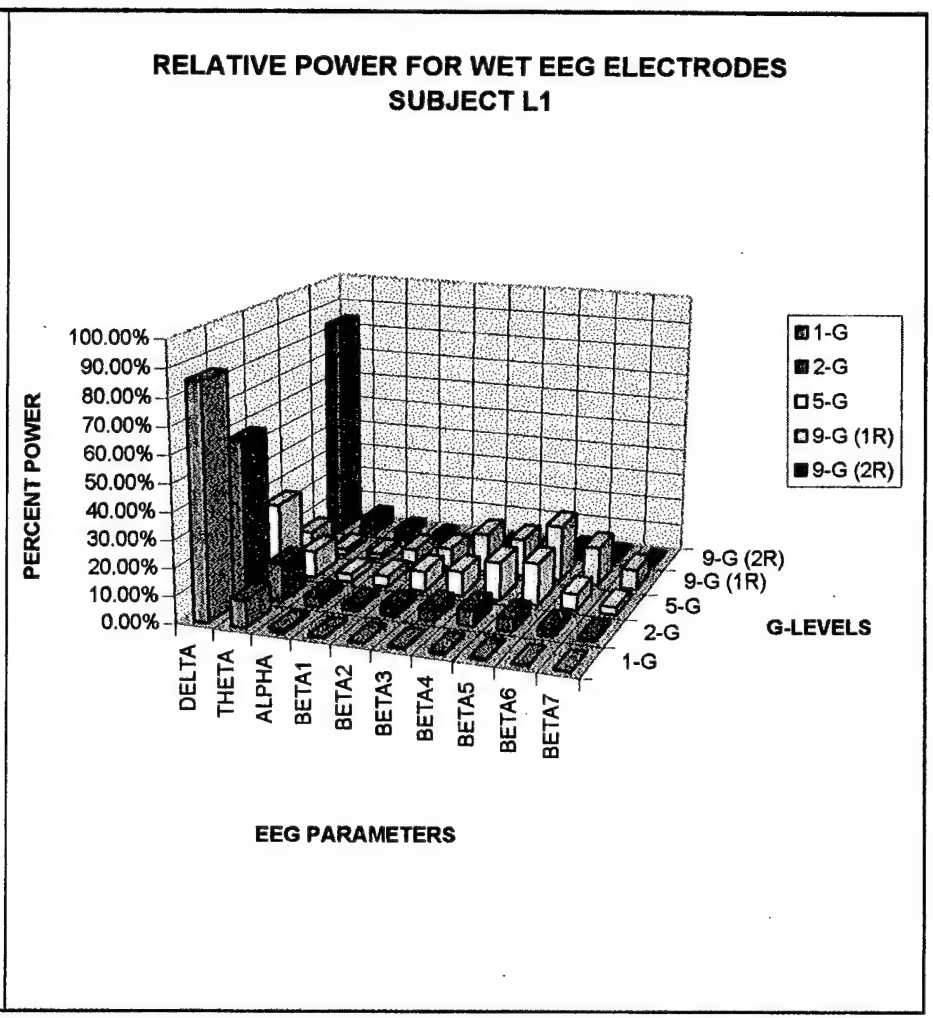
Constant +Gz levels

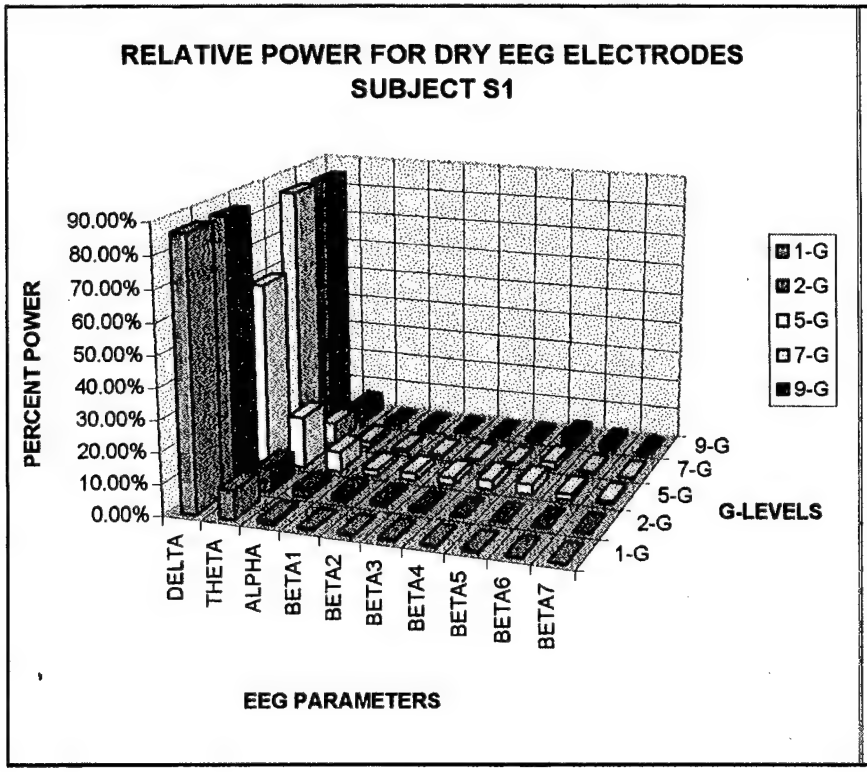

RELATIVE POWER FOR DRY EEG ELECTRODES
SUBJECT D1
PERCENT POWER
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
1-G
2-G
5-G
7-G
9-G
G-LEVELS

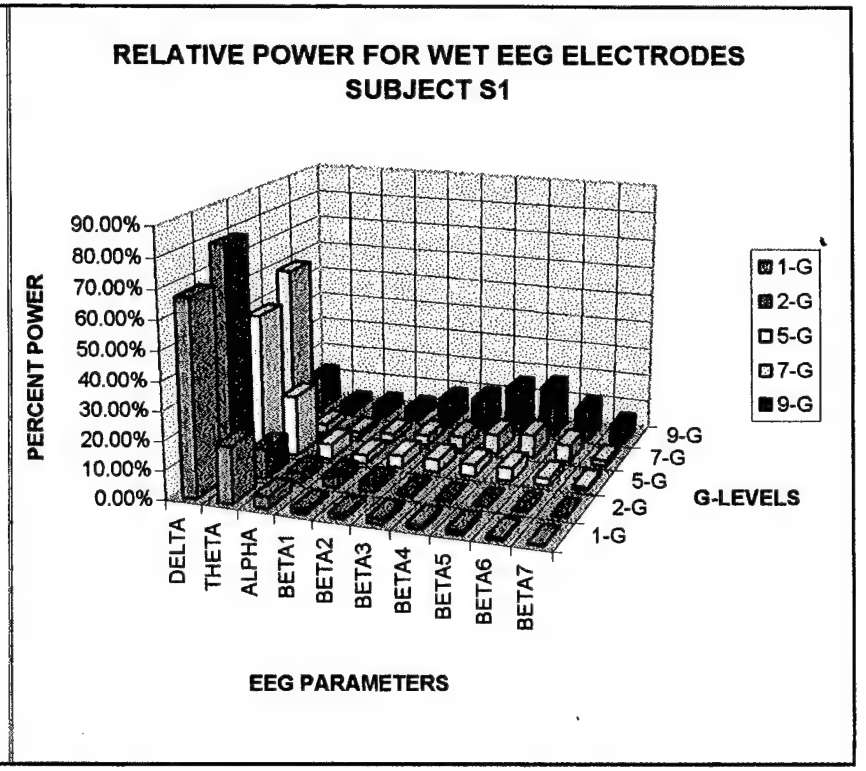

RELATIVE POWER FOR WET EEG ELECTRODES
SUBJECT D1
PERCENT POWER
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
1-G
2-G
5-G
7-G
9-G
G-LEVEL


RELATIVE POWER FOR DRY EEG ELECTRODES
SUBJECT J1
PERCENT POWER
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
9-G
7-G
5-G
2-G
1-G
G-LEVELS
1-G
2-G
5-G
7-G
9-G
RELATIVE POWER FOR WET EEG ELECTRODES
SUBJECT J1
PERCENT POWER
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
9-G
7-G
5-G
2-G
1-G
G-LEVELS
1-G
2-G
5-G
7-G
9-G


RELATIVE POWER FOR DRY EEG ELECTRODES
SUBJECT L1
PERCENT POWER
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
1-G
2-G
5-G
9-G (1R)
9-G (2R)
G-LEVELS

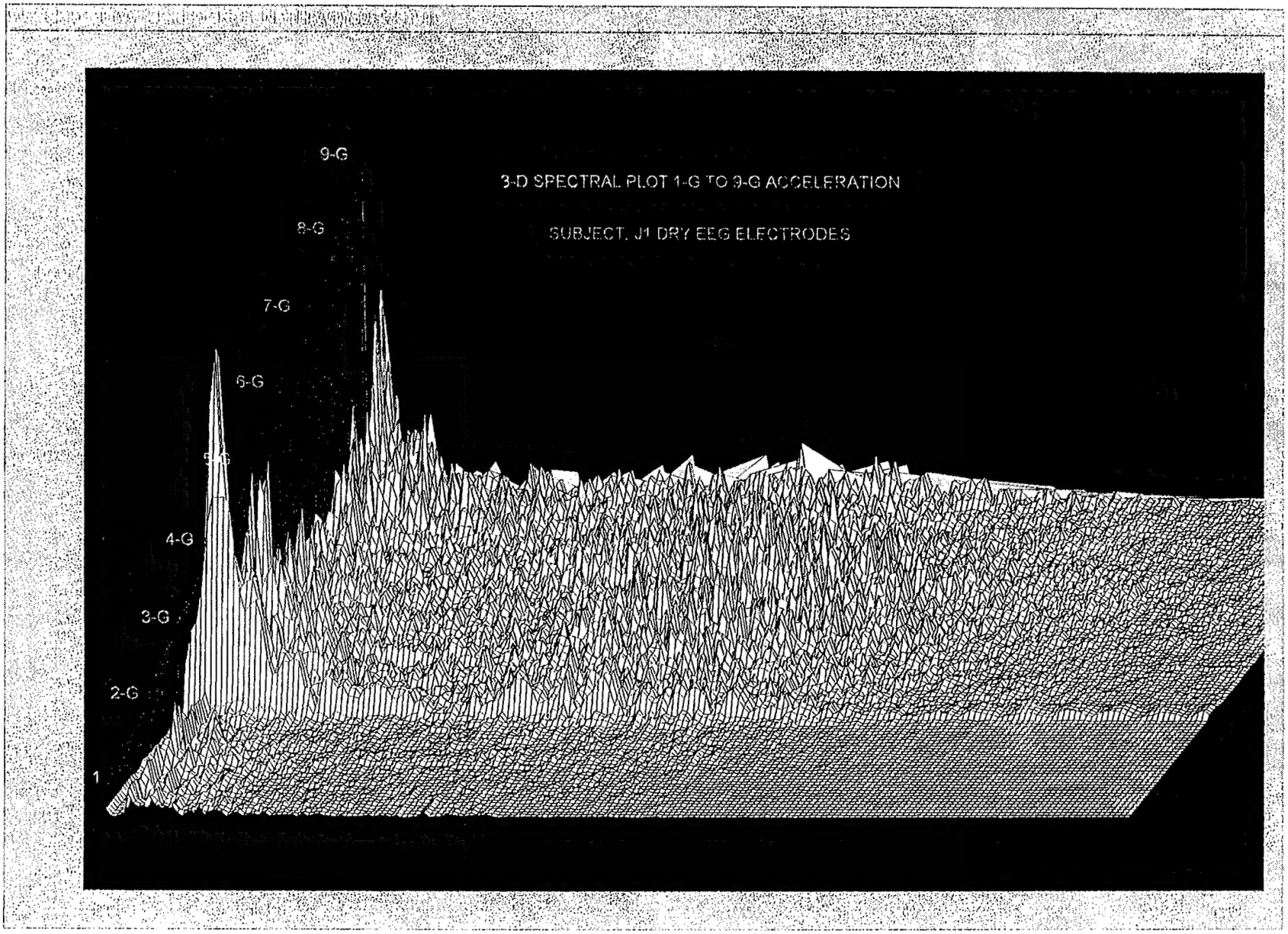

RELATIVE POWER FOR WET EEG ELECTRODES
SUBJECT L1
PERCENT POWER
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
1-G
2-G
5-G
9-G (1R)
9-G (2R)
G-LEVELS

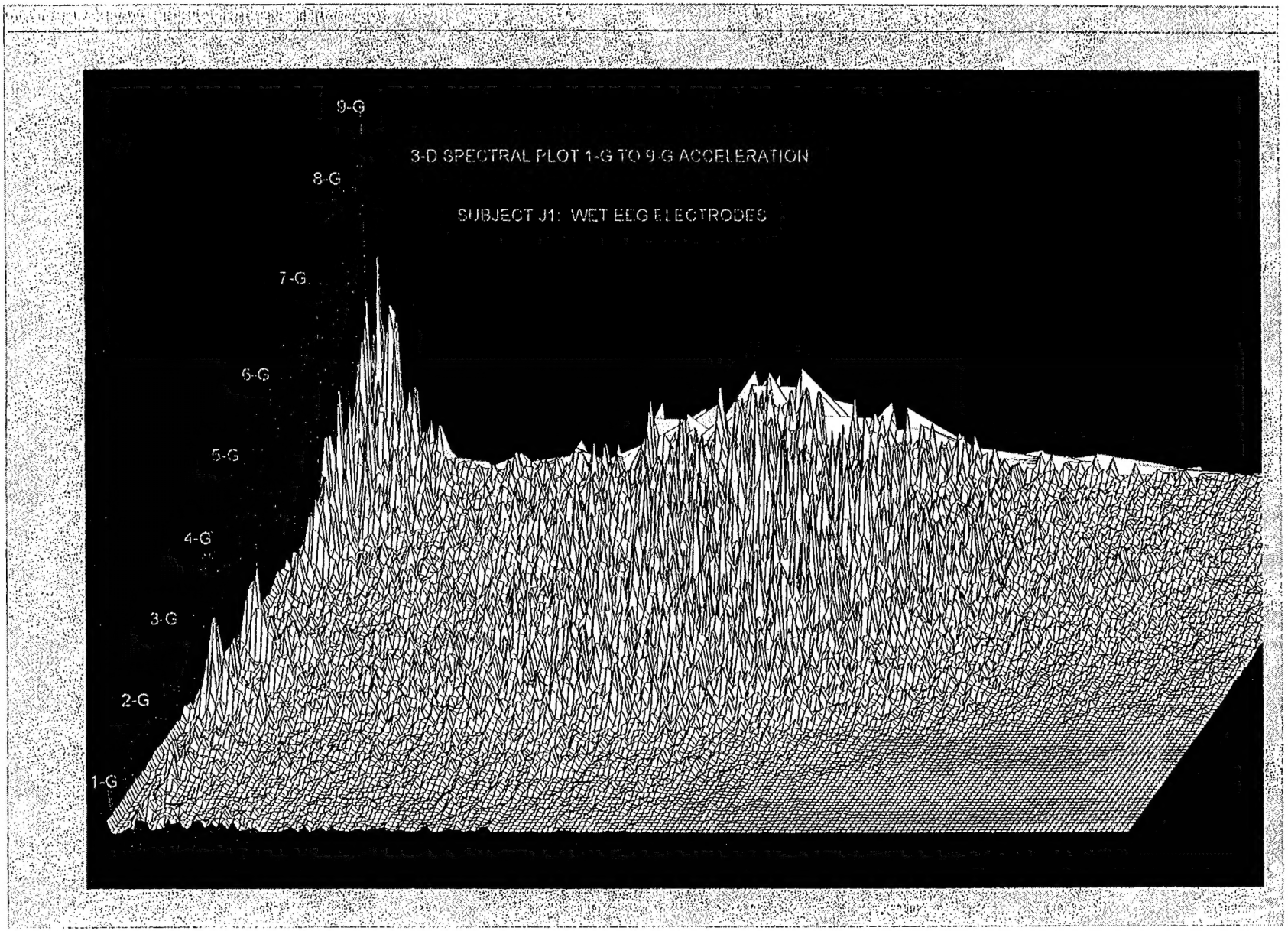

RELATIVE POWER FOR DRY EEG ELECTRODES
SUBJECT S1
PERCENT POWER
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
1-G
2-G
5-G
7-G
9-G
G-LEVELS

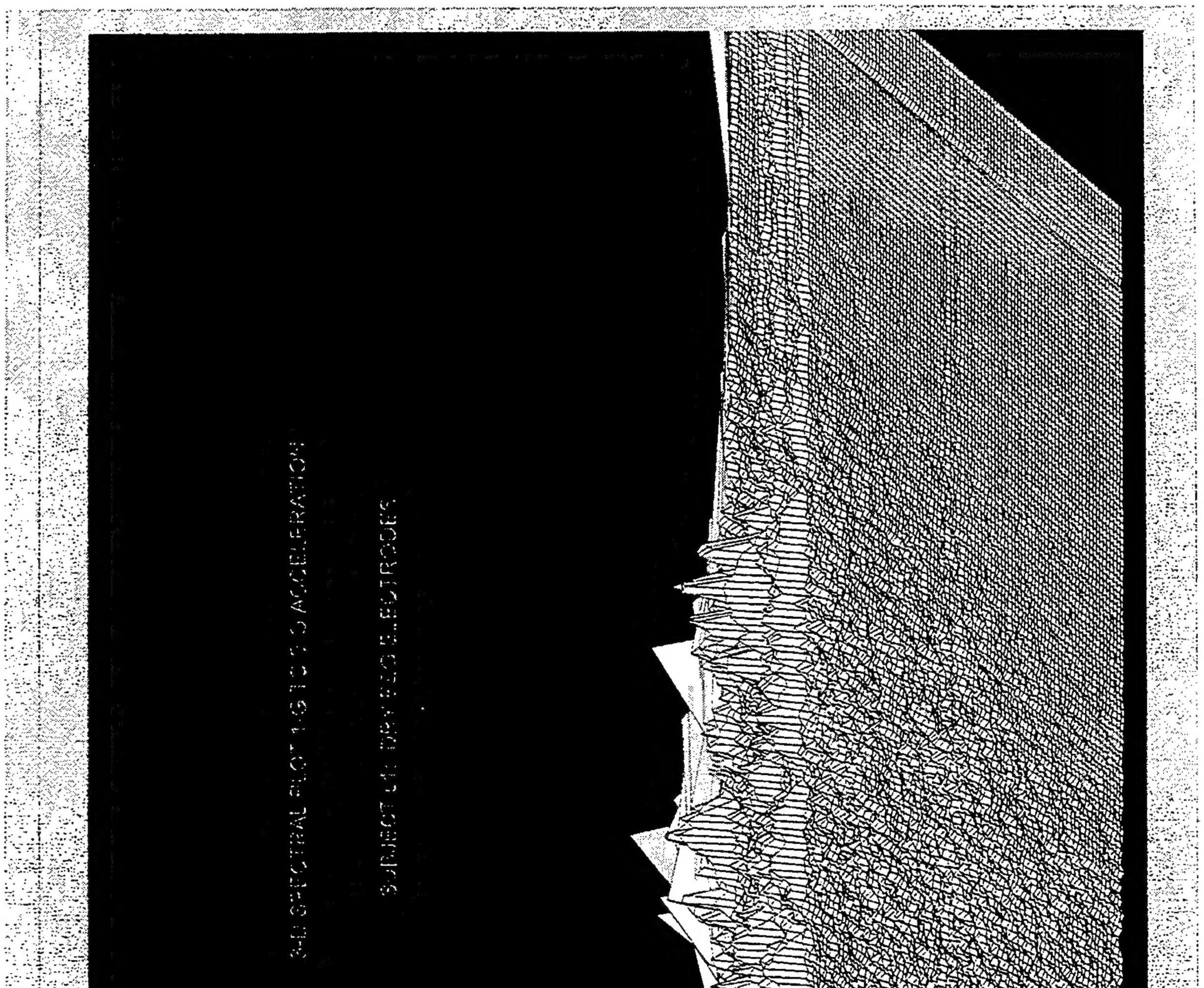

RELATIVE POWER FOR WET EEG ELECTRODES
SUBJECT S1
PERCENT POWER
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
DELTA
THETA
ALPHA
BETA1
BETA2
BETA3
BETA4
BETA5
BETA6
BETA7
EEG PARAMETERS
1-G
2-G
5-G
7-G
9-G
G-LEVELS

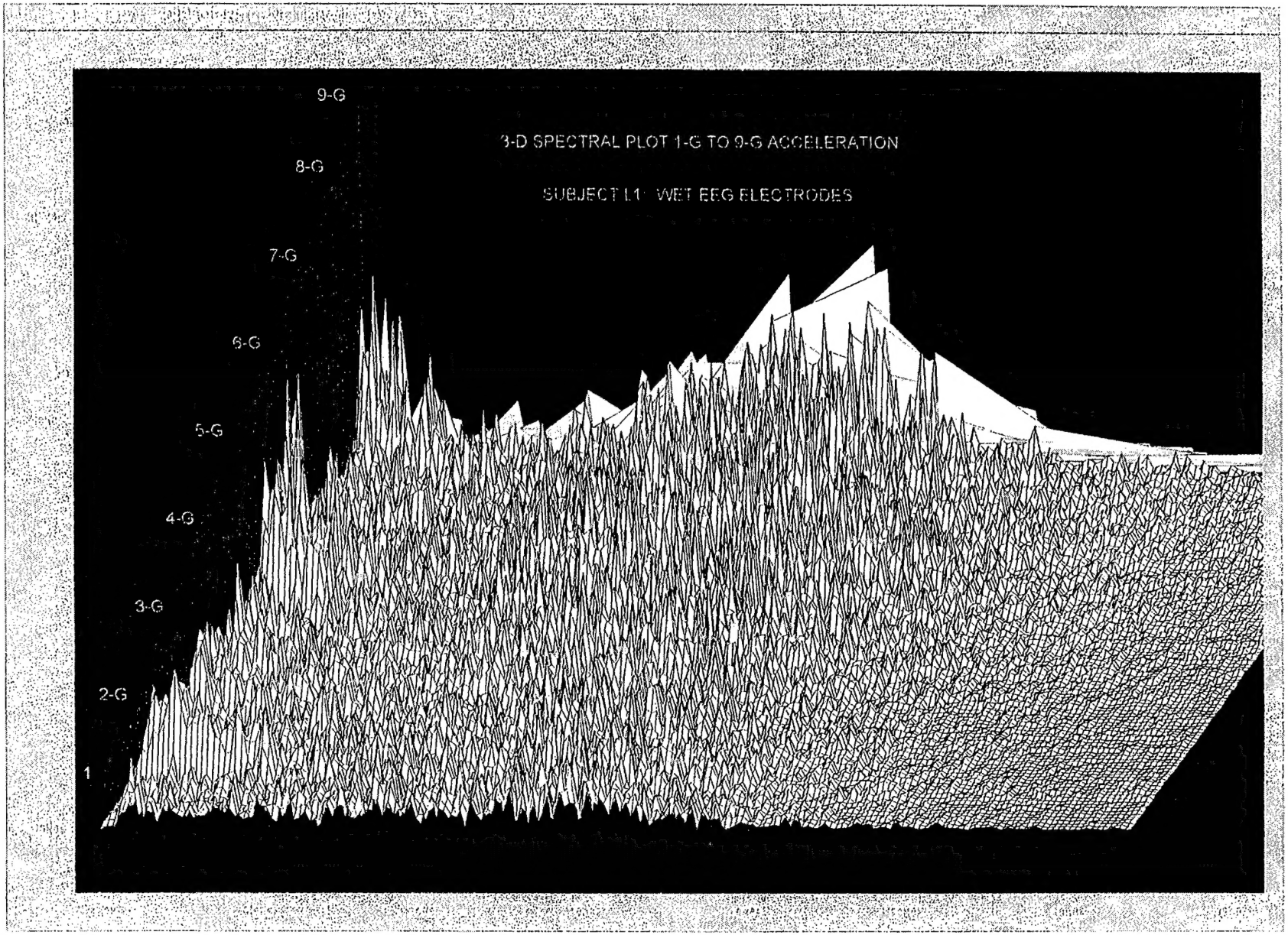
APPENDIX B

3-D Spectral Plots of EEG Signals
During
Acceleration From
+1Gz to +9Gz


3-D SPECTRAL PLOT 1-G TO 9-G ACCELERATION
SUBJECT, J1 DRY EEG ELECTRODES
9-G
8-G
7-G
6-G
4-G
3-G
2-G
1


3-D SPECTRAL PLOT 1-G TO 9-G ACCELERATION
SUBJECT J1: WET EEG ELECTRODES
9-G
8-G
7-G
6-G
5-G
4-G
3-G
2-G
1-G


9-G
8-G
7-G
6-G
5-G
4-G
3-G
2-G


3-D SPECTRAL PLOT 1-G TO 9-G ACCELERATION
SUBJECT L1 WET EEG ELECTRODES
9-G
8-G
7-G
6-G
5-G
4-G
3-G
2-G
1